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## (54) Downhole logging tool

(57) A downhole logging tool for use in gathering data within a borehole and sending those data to monitoring equipment at the surface by means of a fiber optic cable (33c), comprises a system for coupling a data signal into at least one optical fiber of the cable, the system comprising: a light emitting diode (233) for receiving an electrical signal indicative of the data and converting the electrical signal into an optical signal; means (116) for terminating the butt end of the at least one optical fiber of the cable; and

means for mounting the diode (233) for selective longitudinal positioning along a line substantially coaxial with the at least one optical fiber of the cable to position the terminated end of the optical fiber in an abutting relationship with the light emitting diode and couple the optical signals produced by the diode into the optical fiber of the cable for transmission to the surface without requiring any bends in the cable and independent of the length to which the butt end of the fiber has been trimmed in order to terminate it.

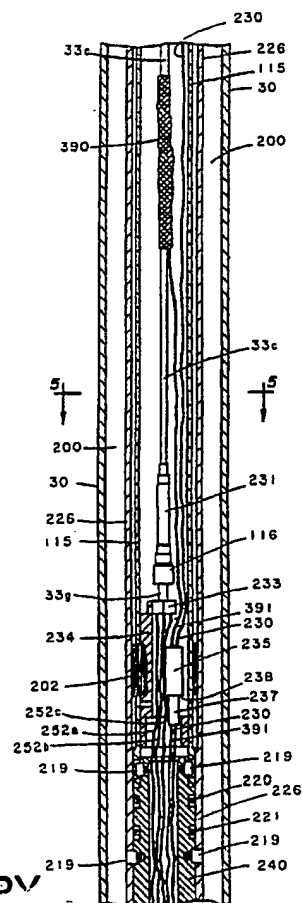
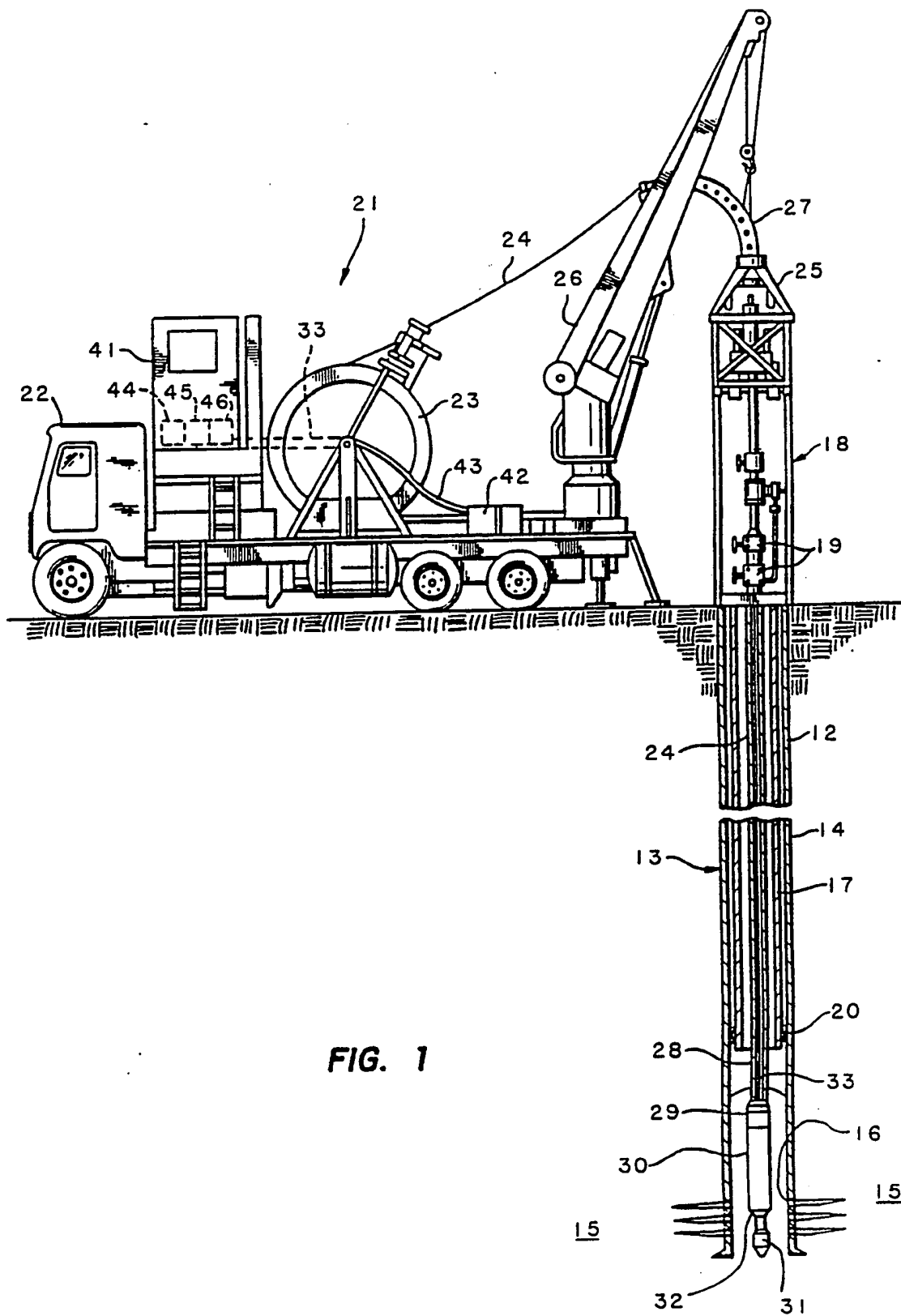


FIG. 3C

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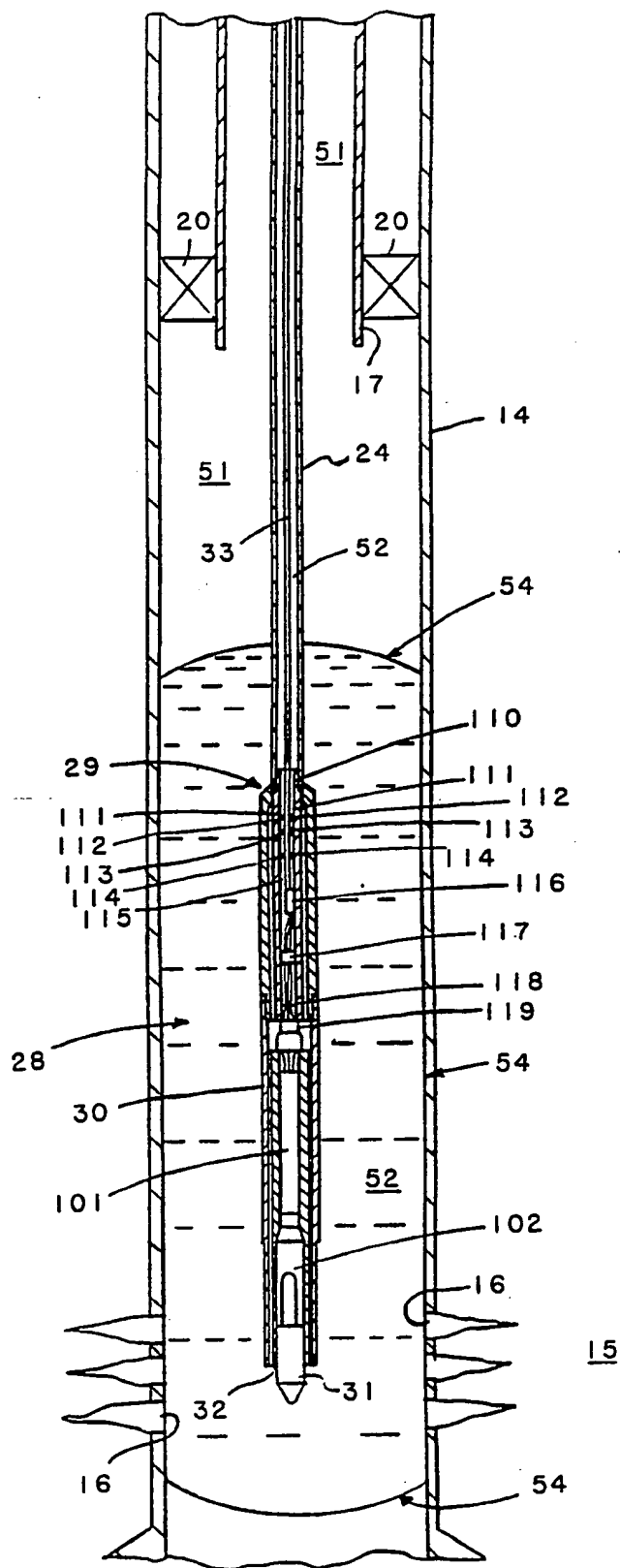


FIG. 2

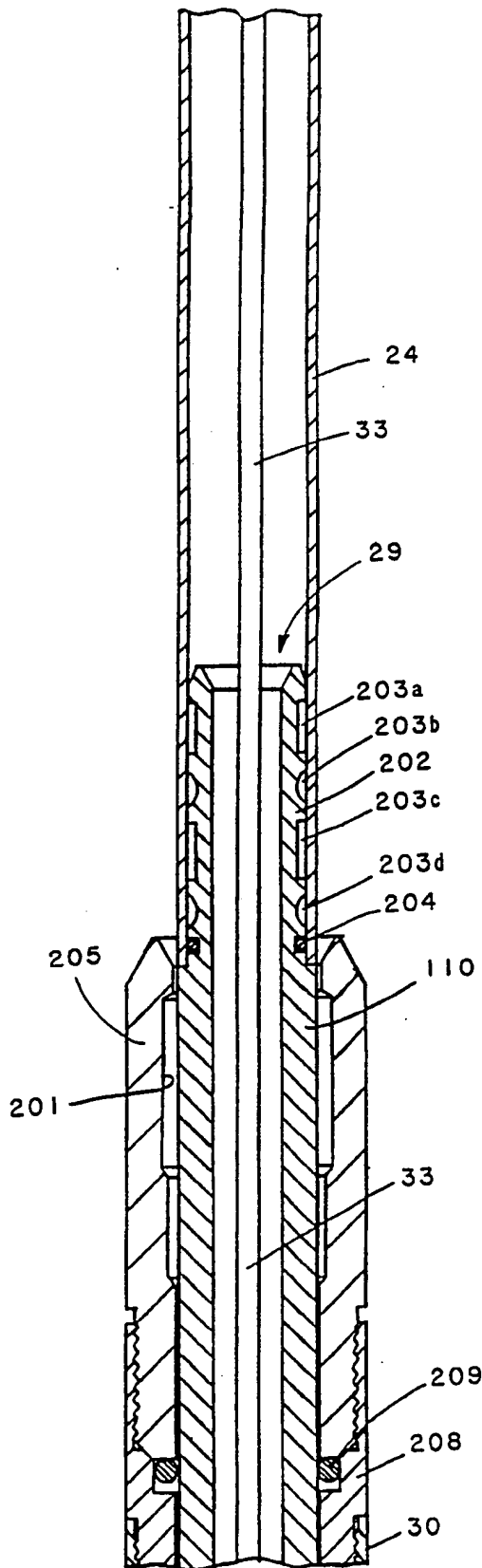


FIG. 3A

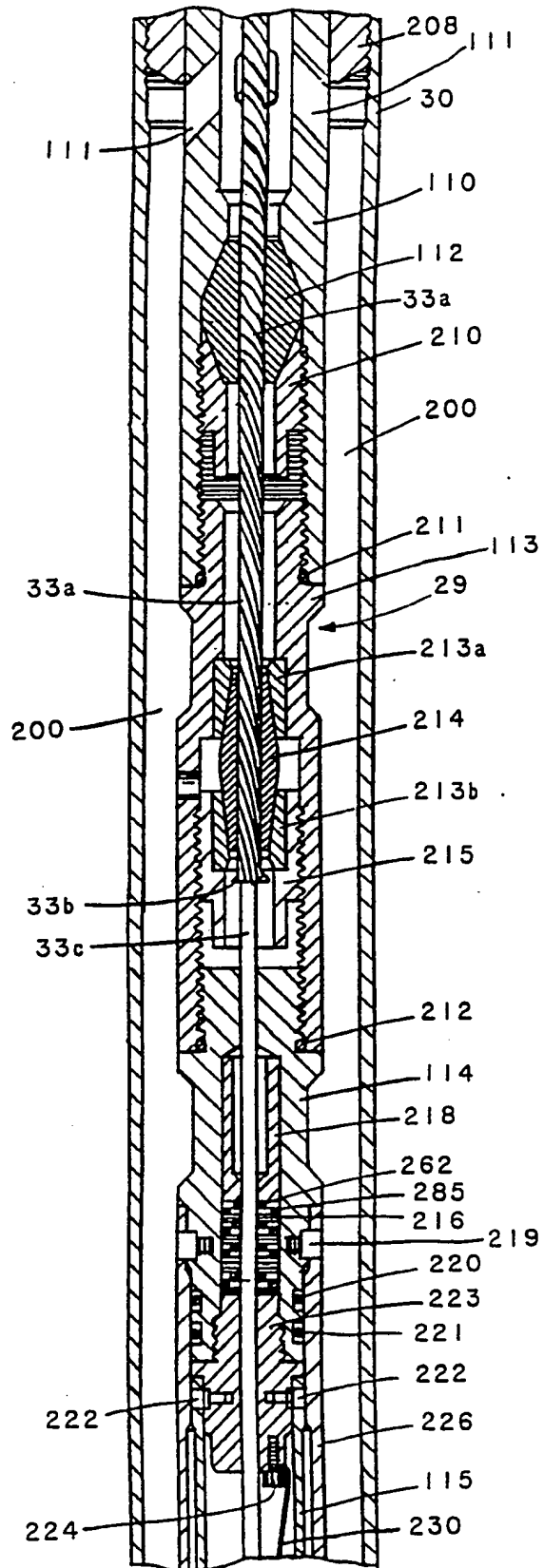


FIG. 3B

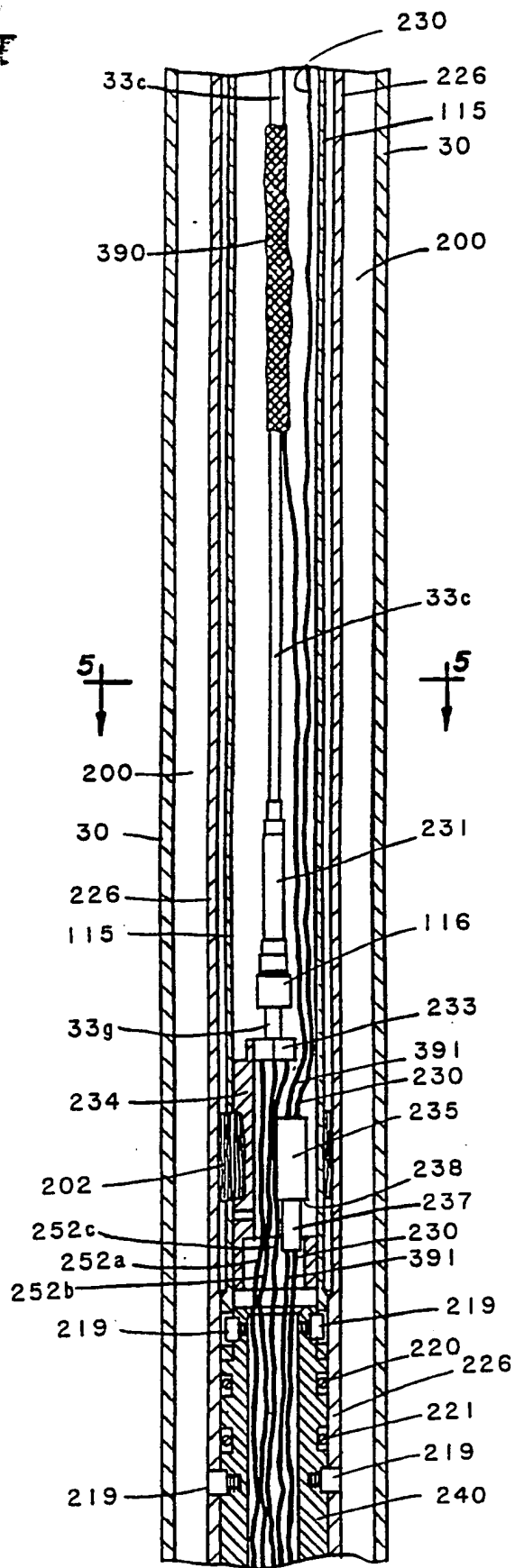


FIG. 3C

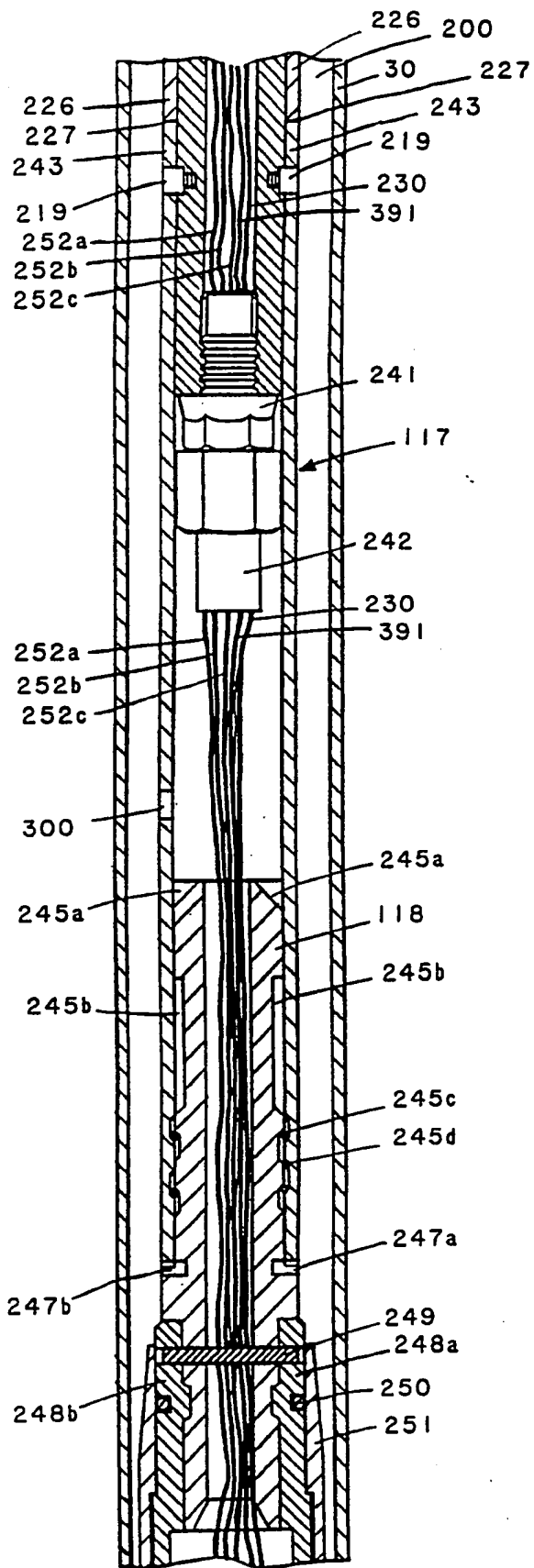


FIG. 3D

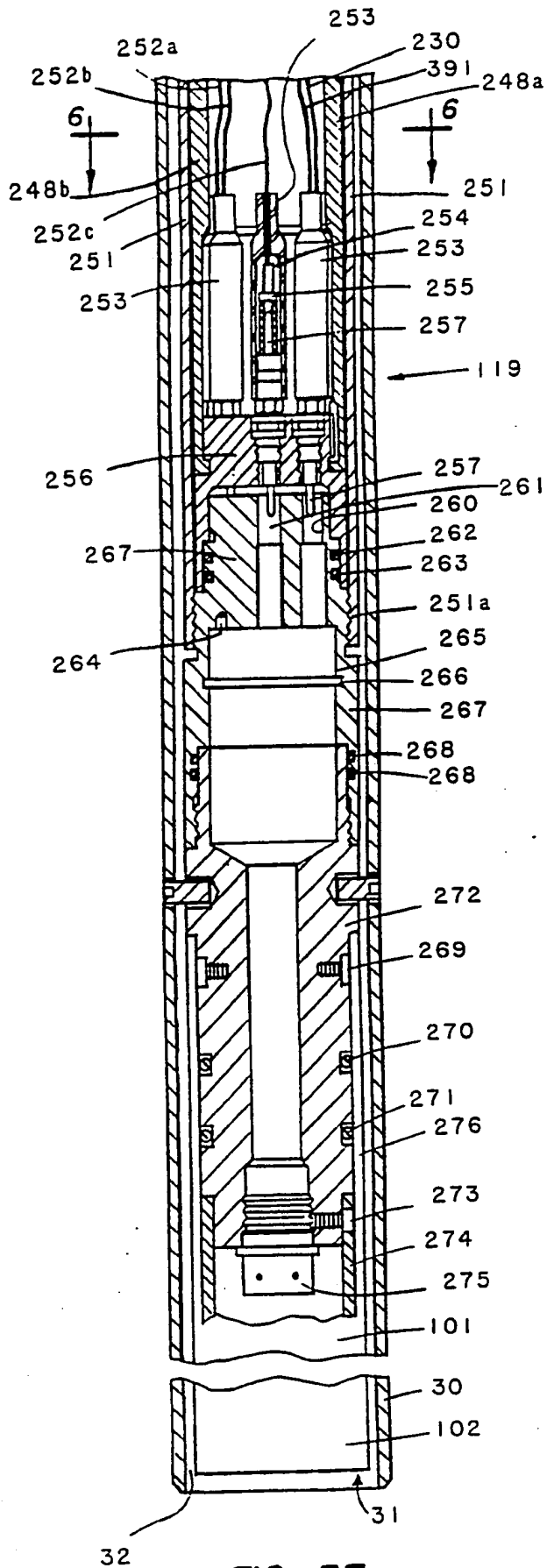


FIG. 3E

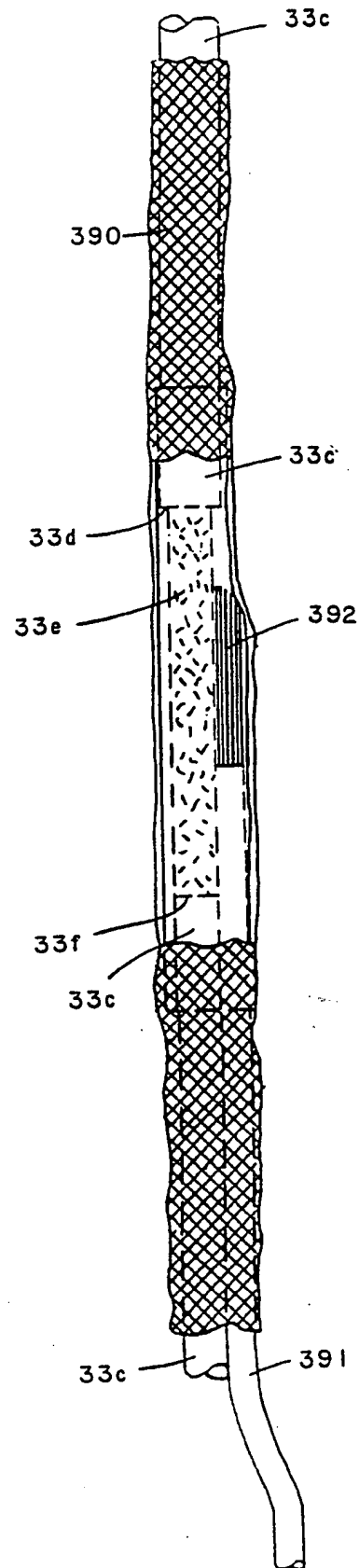


FIG. 4A

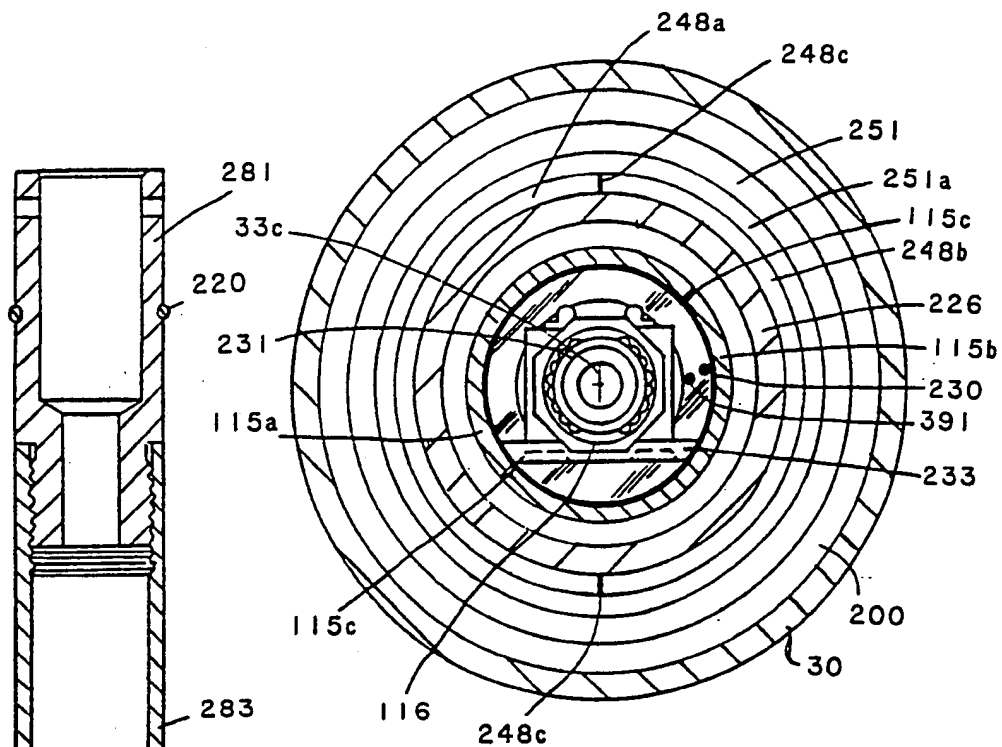


FIG. 5

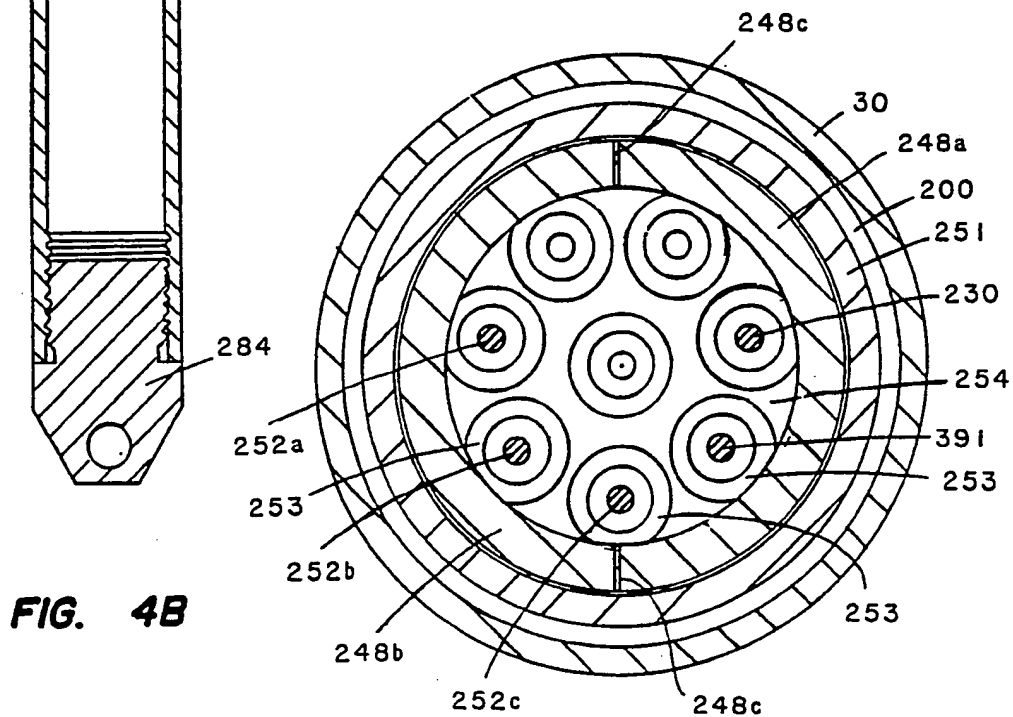


FIG. 4B

FIG. 6

DOWNHOLE LOGGING TOOL

The invention relates to a coiled tubing mounted downhole logging tool, and more particularly, to a modular downhole logging tool for selective attachment to the end of a length of coiled tubing. The invention may be practiced in connection with the maintenance and servicing of oil, gas, geothermal and injection wells. In the drilling and production of oil and gas wells, it is often necessary to obtain at the surface information concerning conditions within the borehole. For example, tools and other objects may become lodged in the borehole during the drilling of a well. Such objects must be retrieved before drilling can continue. When the removal of foreign objects from a borehole is undertaken, known as "fishing", it is highly desirable to know the size, position and shape of the obstructing object in order to select the proper fishing tool to grasp the object and remove it from the borehole. In addition, it is often desirable to confirm the operational condition of a piece of downhole production equipment in order to rely upon that condition in an operational procedure. Such information is very difficult to obtain because of the hostile downhole environment within a borehole filled with opaque drilling fluids.

In the operation and/or periodic maintenance of producing injection wells, it is also frequently necessary to obtain information about the construction and/or operating condition of production equipment located downhole. For example, for early detection of the onset of corrosion damage to well tubing or casing within the borehole enables the application of anti-corrosive treatments to the well. Other maintenance operations in a production well environment, such as replacement of various flow control valves or the inspection of the location and \_\_\_\_\_



condition of casing perforations, make it highly desirable for an operator located at the surface to obtain accurate, real-time information about downhole conditions. The presence of production fluids in the well renders accurate inspection very difficult.

Wireline tools, such as that shown in US Patent No. 3,401,749, have long been used in downhole environments including those which are mounted to a length of coiled tubing, as in US Patent No. 4,877,089, and to such tubing through a coaxial coiled tubing cable head, as in US Patent No. 4,941,349. Moreover, the use of coiled tubing to position a downhole tool and enable the accurate orientation of such a tool is shown in US Patent No. 4,685,516. Various related techniques have been proposed for obtaining at the surface information about the conditions within a borehole. One approach has been to lower an inspection device, such as an optical or acoustical sensor positioned on the end of a section of coiled tubing, into the borehole and produce a slug or "bubble" of optically transparent and/or acoustically homogenous fluid within the borehole to enable the accurate inspection by the inspection sensor attached to the lower end of the tubing. Such a system is shown in US Patent No. 4,938,060.

In addition, in the case of optical inspection sensors of the type shown in US Patent No. 4,938,060, it is also desirable to provide a means for simultaneously cooling the downhole sensor equipment as well as injecting the optically transparent and/or acoustically homogenous fluid within the borehole which enhances the observation and inspection performed by the equipment.

Optical inspection may be by means of a television camera mounted to the lower end of a length of coiled tubing and connected to monitoring and recording equipment at the surface by a transmission line such as a fiberoptic or coaxial cable. However, coiled tubing units represent a very large capital investment and the operator of such a

unit may desire to use it for further applications, such as the injection of nitrogen or other fluids into a wellbore or the attachment of standard electric logging tools. In such cases, providing the downhole inspection equipment as a modular unit which may be selectively connected and disconnected from the coiled tubing would be highly desirable. Further, providing modular downhole inspection equipment which is fluid and pressure sealed from the interior of the length of coiled tubing would provide advantages in the event the inspection module was stuck or lodged downhole and it became necessary to separate the coiled tubing from it in order to first remove the coiled tubing and then recover the lodged equipment with a fishing tool. In addition, for a separable inspection module in which a data transmission means incorporating a coaxial fiberoptic cable is employed to couple the signal from the inspection tool to the surface, sealing of the lower end of the optical fibres of the cable from pressurized liquids within the borehole when the tool is separated is desirable in order to prevent a substantial loss of expensive cable due to intrusions of fluid into the cable fibres due to capillary action.

It would be an improvement in coiled tubing mounted downhole inspection systems if a fluid pressure sealed and transmission line equipped coiled tubing module unit could be plug connectable to the inspection imaging and electronics modules to allow multiple uses of the coiled tubing module as well as to minimize damage to the equipment in the event the tool becomes lodged downhole and necessitates separation of the tubing module from the other downhole equipment. In addition, it would be desirable to provide such a modular inspection system which allows threading of a sealed coiled tubing cable head module through a coiled tubing injector prior to plug connection of the electronics and imaging modules of the inspection tool.

F The parent application No. 9317377.1, from which the present application is divided out, is directed to a downhole inspection tool for attachment to the lower end of a length of coiled tubing having an electrical/fiberoptic cable threaded therethrough.

The parent application No. 9317377.1 is also directed to a system for using a downhole inspection tool to inspect the interior of a borehole.

The present invention provides a downhole logging tool for use in gathering data within a borehole and sending those data to monitoring equipment at the surface by means of a fiberoptic cable. A system for coupling a data signal into the optical fibres of the cable comprises a light emitting diode for receiving an electrical signal indicative of the downhole data and converting the electrical signal into an optical signal. The butt end of the optical fibres of said cable is terminated and the light emitting diode is mounted for selective longitudinal positioning along a line substantially coaxial with the optical fibres of the cable to position the terminated end of the optical fibres in an abutting relationship with the light emitting diode and couple the optical signals produced by the diode into the optical fibres of the cable for transmission to the surface without requiring any bends in the cable and independent of the length to which the butt ends of said fibres have been trimmed in order to terminate them.

For a better understanding of the present invention reference can now be had to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is an illustrative schematic drawing, partially in elevation and partially in cross-section showing a borehole logging tool of the type employed in the present invention;

Fig. 2 is a longitudinal cross-section view of the lower end of a coiled tubing support for a downhole inspection equipment module for use in a logging tool of the present invention;

Figs. 3A-3E show a longitudinal cross-section view of a modular downhole inspection tool for use in a logging tool of the present invention;

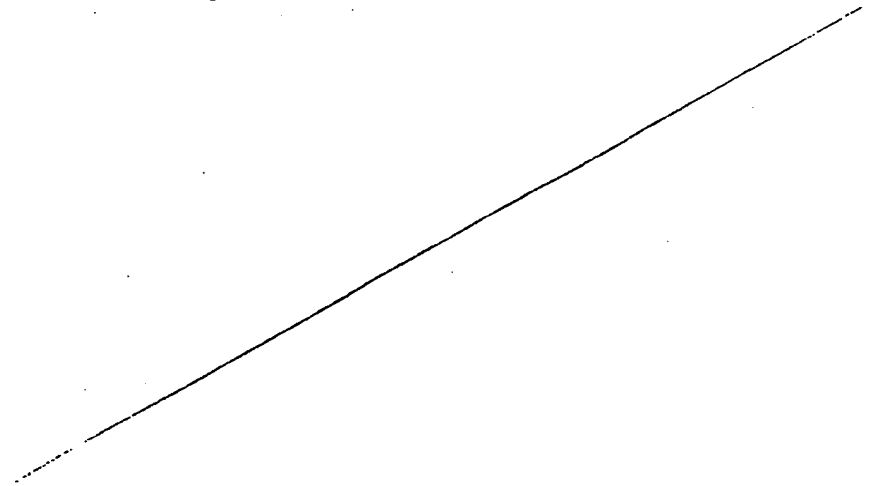
Fig. 4A shows a partially cross-section detailed view of certain wire connections shown in Fig. 3C;

Fig. 4B shows a longitudinal cross-section view of a wiring protection boot attached to the lower end of the tool of Figs. 3A-3E during threading through a coiled tubing injector;

Fig. 5 is a cross-section view taken about the line 5-5 of Fig. 3C; and

Fig. 6 is a cross-section view taken about the line 6-6 of Fig. 3E.

Referring to Fig. 1 there is shown a borehole 12 forming part of a completed production well 13 which includes a casing 14 extending from the surface to the



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production zone 15 of the well. The casing includes a plurality of perforations 16 formed in the wall thereof to allow the influx of production fluids from the producing formation into the borehole for removal at the wellhead. A production packer 20 is positioned between the tubing 17 and the casing 14 above the production zone 15.

A string of production tubing 17 extends from the wellhead production completion equipment 18, known as a "christmas tree", to allow the fluids flowing into the casing 14 from the formation to be received at the surface for collection of production fluids from the well. The various valves 19 at the wellhead 18 control the flow of production fluids brought to the surface through the tubing.

Also as shown in Fig. 1 is an item of production well maintenance equipment 21 known as a coiled tubing unit. This system comprises a truck 22 onto a bed of which is mounted a large mechanically operated coil 23 upon which is wound a continuous length of metal tubing 24 capable of withstanding relative high pressures. The tubing 24 is slightly flexible so as to be able to allow coiling of the tubing onto the reel 23. A coiled tubing injector unit 25 is suspended over the wellhead 18 by a hydraulic crane 26 and is directly attached to the wellhead. The injector 25 includes a curved guideway 27 and a hydraulic means for injecting the coiled tubing 24 down into the well tubing 17 while the well remains under production pressure. A sufficient length of tubing 24 is inserted into the well such that the lower end of the coiled tubing 28 extends out the lower end of production tubing 17 into the region of the borehole inside the casing 14. The production zone 15 is deemed, for purposes of illustration, to be the borehole inspection zone of interest.

Attached to the lower end of the coiled tubing 24 is an inspection tool 28 comprising a coiled tubing cable head subassembly module 29 which is received into a fluid flow tube 30 which is in fluid communication with the

inside of the coiled tubing 24. A fiberoptic and electrical cable 33 is connected to the coiled tubing cable head 29 and extends through the coiled tubing 24 to the receiving and control equipment located at the surface adjacent to the wellbore. Tubing 24 conducts injection fluids to a precise location within the borehole selected by the positioning of injection nozzle 32 and protects the length of the fiberoptic communications cable 33 extending between the inspection sensor sub 31 and the surface. The flow tube also enshrouds an inspection module comprising an electronics module as well as an inspection sensor imaging module such as a video camera assembly located near the lower end thereof to produce video images of subject matter within the casing 14 illuminated by a light head 31. Clear fluid flowing down the coiled tubing 24 exits from a fluid injection nozzle region 32 located at the lower end of the flow tube 30.

Communications and power cable 33 employs optical fibres which, when compared with coaxial cable, both greatly improves the quality of video transmission and also reduces the diameter and weight of the cable. The coiled tubing cable head subassembly module 29 is fitted with equipment, as will be further shown below in connection with Figs. 3A-3E, to seal off the fluid in the tubing from both the electrical and optical cable connections, convert the electrical signal to/from the camera electronics to/from an optical signal, and enable the sealed coiled tubing subassembly module to be removed from the borehole without the camera and electronics modules in the event they become stuck downhole.

The coiled tubing unit 21 carries an operator control housing 41 and a pair of pumps 42 connected to the upper end 43 of the coiled tubing 24 to supply pressurized fluids into the tubing from the surface. Pumps 42 are connected to a supply fluid (not shown). A pump control

console 44 is located within the operator housing 41 and adapted to control the operation of the pumps 42. The upper end of the fiberoptic and electrical cable 33 extending longitudinally along the interior of the coiled tubing 24 is connected to a sensor control unit 45 and a sensor monitor 46 both of which are located within the operator housing 41. When the inspection sensor is a television camera, as in the preferred embodiment, the sensor monitor and control units 45 and 46 may include a video logging unit comprising a fiberoptic video receiver, electrical slip rings, a depth encoder, system power supplies, a communications processor, a character generator, a video typewriter, video monitors and video recorders.

The coiled tubing unit 21 is fitted with the equipment required to seal off the fluid in the tubing from the cable connections, convert the optical signal to an electrical signal, and carry that signal into a cable to the video logging unit. The fiberoptic and electrical cable 33 is used to carry both electrical power and control signals downhole to power the lights and camera and control the camera as well as video signals back uphole from the camera to the sensor control unit 45 and television monitor 46.

Fig. 2, is an enlarged cross-section view, in which various dimensions have been changed for the purpose of illustration, showing the lower end of the coiled tubing 24 and the borehole inspection zone 15. The lower end of the production tubing 17 is sealed on the outside against the inner wall of the casing 14 by means of a production packer 20. Production fluids 51 which flow into the casing 14 through the perforation 16, travel up to tubing 17 toward the wellhead. The production fluids 51 generally comprise oil, salt water and other opaque and frequently non-homogenous fluids.

As discussed above in connection with Fig. 1, the pumps 42 are connected to the upper end 43 of the coiled tubing 24 and to one or more supplies of fluid. From the surface, an optically clear and/or acoustically homogenous

fluid 52, from one of the sources connected to one of the pumps 42, is pumped down the coiled tubing 24 in the direction downhole and toward the nozzle 32 in the lower end 28 of the coiled tubing. This fluid forms an isolated zone or "pill" 54 of optically transparent and/or acoustically homogenous fluid 52 in the region of the inspection tool 28. This enables the television camera of the inspection tool 28 to accurately inspect the interior conditions within the borehole. For example, with the injection of pill 54 of clear fluid the condition of the inner sidewalls of the casing 14 can be optically and/or acoustically inspected without any obstruction from the opaque, non-homogenous borehole fluids 51 normally present within the borehole. Signals produced by the inspection tool 28 are relayed up the fiberoptic cable 33 to the sensor monitoring and control units 45 and 46 within the operator housing 41 located at the surface.

Fluid 52 which is pumped down the coiled tubing 24 under pressure by means of pumps 42 located at the surface, may comprise a number of different fluids depending upon the inspection sensor selected for the particular application and operating conditions. For example, clear fluid media such as water, nitrogen, light hydrocarbons, natural gas, CO<sub>2</sub>, and many others may be acoustically homogenous and optically clear and thus provide a suitable medium for careful and accurate inspection of the downhole conditions by the sensor.

The modular inspection tool 28 connected to the lower end of the tubing 24 includes the coiled tubing cable head subassembly module 29, and an inspection module comprising the electronics module 101 and the television camera and light sensor module 102 all of which are enclosed within the outer flow tube 30. A general overview of the principal components of the modular inspection tool 28 will be given here in connection with Fig. 2, however, the details of the construction and operation of the various elements thereof will be specified below in



connection with Figs. 3A-3E. The cable head subassembly module 29 includes a cable head that is attached to the lower end of the coiled tubing 24. The cable head comprises a crossover adaptor 110 which is crimped onto the end of the coiled tubing and has a plurality of ports 111 drilled through it to allow the optically clear fluid to exit from it into the outer flow tube 30. A rubber pack-off 112 is located in the downhole end of the crossover adaptor 110 and directs the fluid flow into the ports 111. A cable clamp sub 113 is attached to the downhole end of the crossover adaptor 110 to secure the cable 33 mechanically to the cable head.

A cable seal sub 114 is attached to the lower end of the cable clamp sub 113 to prevent pressure and fluid incursion into a diode chassis chamber 115. A fibre optic connector 116 is attached to the lower end of the cable 33 and enclosed within the diode chassis 115 which is attached to the cable seal sub 114. The sealed diode chassis 115 protects the fibre connection, the electrical power connection and the light emitting diode (LED) and its housing (not shown) which converts the video data from the electronics module 101 into a modulated light signal for transmission up the cable 33 to a receiver at the surface. An electrical bulkhead connector assembly 117 is located at the downhole end of the diode chamber 115 and serves as a pressure seal for the diode chamber.

The lower end of the housing of the diode chamber 115 is attached to a bulkhead which has a fishing neck 118 attached to it. The fishing neck 118 is attached to a fishing neck housing with shear wires so that it will be exposed in the event of an emergency separation of the upper coiled tubing cable head subassembly module 29 from the inspection module comprising the lower electronics and camera and light modules 101 and 102. The fishing neck 118 is attached to a quick disconnect connector assembly 119 that allows the electronics and camera modules 101 and 102 to be easily attached and removed from the cable head

subassembly module 29. This quick disconnect connector assembly 119 also allows the electronics and camera modules to be removed and replaced with a temporary boot protector cover that permits the approximately  $1\frac{1}{4}$  inch (32mm) diameter cable head subassembly module 29 to be inserted through the grippers of a coiled tubing injector at the well head. After passing through the injector, the quick disconnect connector 119 is reinstalled so that the somewhat larger diameter, eg. approximately  $1\frac{11}{16}$  inch (43mm) electronics and camera modules 101 and 102 can be reattached to the cable head subassembly module.

The camera lens is located near the light head 31 at the lower end of the camera module 102. The light head 32 may take the external form shown in Fig. 2 or the form of an internal ring as illustrated in Fig. 3E. The outer flow tube 30 surrounds the entire cable head subassembly module 29 as well as the inspection module, comprising the electronics module 101 and the camera module 102, down to exit ports 32 at the lower end of the tool 28. This allows the flow of fluid out of the lower end of the tool housing 28 in the downward direction in front of the camera lens. The fluid then flows back upwardly in the borehole and ensures that there is a region of clear fluid directly in the optical inspection path of the television camera.

Electrical conductors within the cable 33 runs coaxially to the optical fibers thereof and supplies the power to run the downhole electronic module 101, camera module 102 and light 31. A circuit oversees the amount of power required by the television camera and its support electronics 101 and determines the amount of energy to be directed to the light source 31. Electrical power is supplied to the upper end of the cable 33 by the system power supply located in the video logging unit at the surface and may be adjusted by the operator to fine-tune the video images being viewed and recorded.

Referring next to FIGS. 3A-3E, there is shown a detailed longitudinal cross-section view of a downhole inspection tool 28, and especially the coiled tubing cable head subassembly module 29 thereof.

The lower end of the coiled tubing 24 is received onto the upper end of the cable head cross-over adapter 110 comprising a reduced cylindrical neck section 202 having a plurality of circumferential recesses 203a-203d longitudinally spaced from one another. The circumferential recesses 203a and 203c are filled with epoxy and the cylindrical wall of the coiled tubing is crimped down into the recesses 203b and 203d to form a firm sealed connection therebetween. An o-ring 204 assists in sealing the lower end of the coiled tubing 24 onto the neck of the cross-over adapter 110. An internal fishing neck 205 includes a circumferentially extending interior recess 201 for engagement by a fishing tool lowered from the wellhead to grip the fishing neck 205 and withdraw it from the borehole in certain situations.

The cross-over adapter 110 extends down through the upper end of a seal sub 208 and is fluid sealed thereagainst by an o-ring 209. The lower edge of the seal sub 208 connects to the upper end of the outer flow tube 30 and terminates just above a plurality of orthogonally spaced flow ports 111 formed in the cross-over adapter 110. The ports 111 allow clear fluid flowing from the coiled tubing 24 down through the interior of the cross-over adapter 110 to exit and continue on down along the annular region just inside the walls of the flow tube 30.

The construction of the fiberoptic/electrical cable 33 extending down the interior of the coiled tubing 24 preferably comprises a centrally located core of optical fibers surrounded by a stainless steel tube which is then covered with a first layer of polypropylene insulation. A small amount of silicone grease may optionally be included as a lubricant and support agent for the fibers within the tube. Next, a layer of braided copper conductive strands surrounds the inner polypropylene insulation which is in turn covered by an additional layer of polypropylene material to protect and insulate the copper braid. Finally, two layers of high tensile strength steel strands are wound in a reverse lay to form an outer protective layer around the polyethylene insulative layer which provides both longitudinal strength to the cable 33 as well as an additional conductive path. While the above construction of the cable 33 is preferred, other configurations could be employed. For example, only one optical fiber could be included in the core of the cable if that is sufficient to carry the data required for the particular application and, thus, the term optical "fibers" as used herein should be

construed as including a single optical "fiber". Other embodiments of suitable cables could be adapted for use in the present invention, such as the cable shown in co-pending patent application GB 2255995 which is hereby incorporated by reference.

One of the functions of the cable head subassembly module 29 of the present invention is to provide means for terminating various layers of the cable 33 and adequately sealing various parts of it from intrusion by borehole fluids while at the same time avoiding bends in the optical fibers of the cable and thereby preventing the introduction of optical attenuation. The outermost layer of steel strands surrounding the cable 33 extend through an axial opening within a cable pack-off 112 formed of resilient material and positioned within the interior of the crossover adapter 110. The upper end of the pack-off 112 closes the lower end of the central aperture of the crossover adapter 110 and forces fluid to exist through the ports 111. A pack-off compression nut 210 is threadedly received within the interior of the crossover adapter 110 and, in response to rotation, the nut 210 applies axial pressure to the cable pack-off 112. The pack-off 112 tightly squeezes the exterior surface of the steel strand portion 33a of the cable 33 to seal it against the flow of water and debris and divert the flow of the optically clear fluid flowing into the crossover adapter 110 out through the ports 111. A lock spring 211 serves to rigidly engage the lower end of the crossover adapter 110 with the upper threaded end of a cable clamp sub 113 within which is received an end cone 213. An

upper end cone 213a is longitudinally fixed within a cavity formed by recessed shoulders within the cable clamp sub 113 and includes a circular opening in the upper end thereof to allow passage of the steel stranded exterior surface 33a of the cable 33. A double cone 214 is formed of electrically conductive gripping material such as stainless steel and has opposed tapered ends received into the tapered cone shaped interior walls of the upper end cone 213a and a lower end cone 213b. A cable clamp nut 215 is threadedly received into the interior of the cable clamp sub 113 and rotation of the nut 215 decreases the spacing between the upper end cone 213a and the lower end cone 213b causing the double cone 214 to compress its inner walls against the stranded outer steel wires 33a of the cable to grip and mechanically hold the cable in place and keep it from slipping longitudinally within the cable clamp sub 113. Just below the lower edges of the double cone 214, the stranded armor wires 33a of the cable 33 are stripped back and cut away at 33b to leave a polyethylene covered insulated layer 33c extending on down the sub.

A lock spring 212 locks the threaded lower end of the cable clamp sub 113 to the upper threaded end of a cable seal sub 114. An elongate stainless steel cable seal insert 218 serves as a spacer and retains the sealing components 262, 285, and 216. Below the cable seal insert 218 is located a cavity within which is positioned a stack of fluid and pressure sealing members comprising a stacked array of small diameter o-rings 262, somewhat larger diameter o-rings 285 and cable seal holders 216. Abutting the lower edge of the stack of sealing members within the cable seal sub 114 is a compression nut 223 which is threadedly received and

tightened into the threaded lower end of the cable seal sub 114. The nut 223 retains the stack of sealing members 262, 285, and 216 which seals against the outside polypropylene surface 33c of the cable 33 and seal borehole pressure and fluid from passage into the interior of a diode chassis housing 226 fixed to the lower end of the cable seal sub 114 by socket head screws 219. The lower outside edges of the cable seal sub 114 are sealed against the upper inner edges of the diode chassis housing 226 by an o-ring 220 and a backup ring 221. When the compression nut 223 of the cable seal sub 114 is threaded into position, the diode chassis 115 is affixed to the compression nut 223 by means of flathead screws 222. A socket head screw 224 is used to connect a ground wire 230 to the compression nut 223. The diode chassis 115 is integrally connected to the metal body components of the cable head subassembly 29 which is electrically connected to the stranded steel conductors 33a of the cable 33. The diode chassis 115 is a sealed chamber formed by the two split-halves of a cylindrical tube which allows it to be separated into two halves along a longitudinal axis for ready access to the various cable and diode connections contained within the protected interior thereof. In addition, since electrical power is carried in the cable 33 with one conductive member being formed by the steel strands 33a and the other being formed by the copper braiding 33e within the polyethylene layer 33c, the wire 230 forms a solid electrical ground connection.

Referring next to FIG. 3C, the hatched region 390 represents a heat shrinkable outer insulative covering overlying a soldered electrical connection. Referring briefly to FIG. 4A, the region underlying heat shrink 390

is shown in greater detail. There it can be seen that the polypropylene insulative layer 33c of the cable 33 is terminated at point 33d leaving exposed a length of the braided copper shielding 33e forming the power conductor within the cable 33. The braided copper conductor 33e is only exposed over a short distance and the polypropylene insulative layer 33c begins again at 33f. A power wire 391 has its end 392 stripped bare, fluxed and soldered to the stranded copper braiding 33e to provide a secure mechanical and electrical connection therebetween. Thereafter, the heat shrink tube 390 placed over the entire connection, is heated and shrunk tightly down onto the solder connection to insulate and protect it from moisture which may inadvertently enter the system.

Referring back to FIG. 3C, the polypropylene outer coating 33c of the fiberoptic cable extends longitudinally within the split halves of the diode chassis 115 alongside the power conductor 391 and the ground conductor 230. The fiberoptic portion of the cable 33 is terminated by means of an ST multimode fiberoptic connector 116 which may, for example, be Model No. 501380-1 ST connector, manufactured by AMP, INC. of Harrisburg, Pennsylvania. Within the fiberoptic connector 116 the polypropylene insulation layers, copper braid, and steel tube protecting the optical fibers is stripped away to expose the fibers 33g the butt end of which are mounted contiguous to a light emitting diode 233 mounted on a diode holder 234. Once the termination within the multimode connector 116 is complete, a heat shrink 231 is applied therearound and shrunk to protect the finished connection. Located near the diode holder 234 is an electrical connector assembly 235 which incorporates a female socket 238 into which a male



terminal plug 237 is fitted for electrical connection of power and ground circuit wires 230 and 391. The receptacle and plug 238 and 237 allow ready connection of the power and ground leads in the event of trouble shooting and maintenance activities. The diode holder 234, along with the diode 233, are mounted for longitudinal movement and selective axial positioning within the diode chassis 115. This enables the fiberoptic cable 33, and particularly the portion of the cable 33c between the lower end of the cable seal sub 114 and the multimode connector 116 to be positioned within the diode chassis 115 along a straight, linear axis without any significant bends therein which might produce optical attenuation of the signal being conducted by the optical fibers. That is, the cable 33c can be arranged in a perfectly linear configuration and then the diode 233 moved into an abutting relationship against the butt end of the optical fibers in the region 33g by adjusting the axial position of the diode holder 234. This feature also facilitates maintenance of the fiberoptic cable 33 by enabling the butt end of the optical fibers at 33g to be periodically dressed whenever necessary by cutting off squarely the ends of those fibers to optimize the optical transmissivity thereof. The longitudinal position of the diode holder 234 is then adjusted so that the diode 233 is positioned squarely abutting the butt end of the somewhat shorter cable after trimming. Several wraps of glass tape 202 are placed in the region between the diode holder 234 and the inner side walls of the diode chassis 115 to provide frictional securement of the diode holder 234 at a chosen location. Thus, the longitudinal moveability of the diode holder 234 within the diode

chassis 115 provides an essentially infinitely adjustable fiberoptic termination within the system.

Referring briefly to the cross-section drawing of FIG. 5 taken about the lines 5-5 of FIG. 3C, there is shown the outer flow tube 30 within which is contained an annular fluid flow space 200 extending the length of the tool. The outwardly tapering upper edges of a collar 251 and the upper edge thereof 251a surround a pair of longitudinally split sleeves 248a and 248b which are divided into two semi-cylindrical halves fitted together at opposing joints 248c to form a cylindrical enclosure as will be further described below. The diode chassis housing 226 is spaced from and surrounds the diode chassis 115 which is split into two semi-cylindrical halves 115a and 115b and are fitted together at junctions 115c to form an enclosed sealed cylindrical housing for the diode. The two insulated electrical conductors comprising the power wire 230 and the ground wire 391, lie in the annular space between the diode chassis housing 226 and the diode chassis 115 comprising split halves 115a and 115b. Positioned within the diode chassis 115a-115b the diode holder 234 mounts a diode 233 into which is terminated the lower butt end of the fiberoptic cable 33g. The polypropylene layers, copper braid, and steel tube of the fiberoptic cable 33 is stripped away and terminated by means of the ST multimode connector 116 around which is positioned a heat shrink 231.

Returning to FIG. 3C, a pair of signal wires 252a and 252b, along with a chassis ground 252c, provide a driving signal to the diode 233 for converting video output signals from electrical to optical signals capable of being transmitted on the fiberoptic cable 33. A

connector bulkhead 240 is received within the lower portion of the diode chassis housing 226 and is sealed against the inner walls thereof by a pair of o-rings 220 and backup rings 221. In addition, the diode chassis housing 226 is secured to the connector bulkhead 240 by means of socket head screws 219. The diode chassis housing 226 is the pressure and tension bearing member of the assembly and once the split halves of the diode chassis 115a and 115b are assembled the diode chassis housing 226 is slid into place thereover and placed onto the upper end of the connector bulkhead 240. The diode chassis housing 226 may be rotated with respect to the connector bulkhead 240 so that the screw holes are aligned and the socket head screws 219 are placed into position to fix the members with respect to one another.

Referring next to FIG. 3D, an electrical connector bulkhead assembly 117 comprises a connector plug 241 which is a bulkhead type electrical connector that is pressure tight and allows passage of the electrical power conductors 230 and 391 as well as the LED signal conductors 252a, 252b and 252c while protecting the interior of the connector bulkhead 240 from outside fluids and pressures. A connector socket 242 is fitted into the connector plug 241 so that the electrical interconnection between conductors 230, 391, 252a-c is solidly made yet subject to disconnection upon longitudinal separation between the plug 241 and the socket 242.

The diode chassis housing 226 ends at 227 at which it abuttingly joins the upper edges of a fishing neck housing 243. A pressure equalization opening 300 is formed in the sidewall of the fishing neck housing 243, and the lower open end thereof receives a fishing neck

118. The upper end of the fishing neck 118 includes tapered upper edges 245a for aid in the assembly of the structure and attachment of a fishing tool, a central set of recesses 245b for engagement by a fishing tool, an upper shear wire 245c and a lower shear wire 245d for securing the fishing neck 245 on the lower end of the fishing neck housing 243. A pair of dowel pins 247a and 247b prevent rotation of the fishing neck 118 with respect to the fishing neck housing 243. The shear wires 245c and 245d serve as shear wires so that the tool separates at this point in the event of an emergency such as when the outer flow tube 30, and the components mechanically connected thereto, is stuck downhole. In such a case, a preselected upward force on the cable head subassembly 29, which includes the cross-over adapter 110, the cable clamp sub 113, cable seal sub 114, diode chassis housing 22b and fishing neck housing 243, will shear the wires 245c and 245d and allow that housing 243 to be pulled upwardly separating it from the fishing neck 118 leaving the neck exposed. The entire cable head subassembly 29 can then be withdrawn from within the outer flow tube 30 and pulled to the surface of the borehole. The fishing neck 118 is attached to the upper end of a pair of split sleeves 248a and 248b which are enclosed within the collar 251. An o-ring 250 holds the split sleeves 248a and 248b together to facilitate assembly.

Referring next to FIGS. 3D and 3E, during assembly the split sleeve collar 251 is positioned upwardly from the split sleeves 248a and 248b and once the two halves of the sleeves are assembled, the collar 251 is pulled down over those split halves. Dowel pin 249 prevents the split sleeves 248a and 248b from rotating. The lower

edge of the collar 251a receives a lower connector housing 267 which contains a plurality of contact assemblies 260 each of which contains a female contact pin 260 which fittingly receives a single pin of a feedthrough assembly 257 mounted within an upper housing 256. The power and signal connections 230, 391, 252a-c are each connected, respectively, to a contact socket assembly 255 enclosed within an insulative contact boot 253 which protects the assembly once the plug connection is made. A teflon insert 254 serves to insulate and support the contact boot 253 from collapsing. A plurality of feedthrough contact socket assemblies 255 are provided and enable each circuit which contains either a signal, power or a ground connection to be passed out from within the coiled tubing cable head subassembly 29 and adapted for a simple plug connection to the electronics and camera modules 101 and 102 by means of the quick disconnect connector assembly 119. Electrical connections within the assembly 119 are made to the electronic module 101 of the tool through the female contact pin assembly 260 contained within the lower connector housing 267 which is sealed to the upper housing 256 by o-rings 262 and 263. A roll pin 264 keeps the insulator block 265 from rotating within the housing. The o-ring 263 keeps pressure and fluid flow from getting into the area where the connections are made.

Referring briefly to FIG. 6, there is shown a cross-sectional view taken about the lines 6-6 of FIG. 3E. There, the system is depicted which includes the outer flow tube 30 within which is positioned the collar 251 defining an annular region 200 for the flow of fluid therebetween. The pair of split halves comprising split sleeves 248a and 248b joined at junctures 248c enclose

the electrical connections within a fluid and pressure sealed housing area. The split sleeves 248a and 248b enclose overlying boots 253 which protect plug connectable electrical connections of the wires 230, 391 and 253a-c as well as certain dummy connectors in those positions which are not used. The upper housing 254 comprises the remainder of the connector.

Referring again to FIG. 3E, a retaining ring 266 keeps the insulator block 265 within the housing from coming out. The lower connector housing 267 is mounted to a camera adapter bulkhead 272 by threaded engagement therewith and is sealed thereto by means of o-rings 268. The electronic module 101 comprises an electronics housing 276 containing an electronics assembly 274. The assembly 274 is attached to the lower end of the camera adapter bulkhead 272 by a socket head screw 273 while the electronics housing 276 is attached by socket head screws 269 and sealed thereto by o-rings 270 and 271. A connector receptacle 275 plugs into a mating receptacle on the electronics assembly 274. The outer flow tube 30 is installed after the cable head subassembly, electronics and camera modules are all in place and connected and the flow tube 30 is mechanically pinned to the camera adapter bulkhead 272 by set screws 206.

FIG. 4B depicts an injector feed through boot protector for the coiled tubing cable head subassembly 29 and comprises a split nut boot protector portion 281, a tube boot protector portion 283 which is threadedly joined thereto, and a plug boot protector end piece 284 which threadedly engages and closes the lower end. An o-ring 220 secures the split nut for assembly. The outside diameter of the boot protector of FIG. 4B is approximately the same as that of the fishing neck

housing 243 (FIG. 3D). In use, the split sleeve collar 251 is moved upwardly from around the split sleeves 248a and 248b. The split sleeves 248a and 248b are separated from one another to expose the quick disconnect connector assembly 119. The contact protection boots 253 and the contact socket assemblies 255 are plug disconnected from the upper ends of the feed through pins 257. Thereafter, the connector 119 and all the equipment below the fishing neck 118 is removed and replaced by the injector feed through boot protector of FIG. 4B by placing the split nut halves over the dowel pin 249 and then threading 283/284 over the split nut, containing and protecting the contact boots. Then the entire coiled tubing cable head subassembly module 29 and the attached coiled tubing can be inserted through the grippers of a coiled tubing injector. The plug connectable wires and contact assemblies 255 are received into the cavities of the boot protector portions 281 and 283 and pass readily through the injector. Once the cable head subassembly is passed through the injector, the boot protector is removed and the quick disconnect connector assembly 119, along with the other equipment including the electronics and camera modules 101 and 102, reinstalled for insertion downhole into the wellbore at the end of the coiled tubing.

As can be seen from the above description, the inspection tool is provided with means enabling the emergency separation of the inspection equipment from the coiled tubing cable head subassembly 29 in the event a portion of the equipment becomes stuck down in the well. In such a case strong upward force on the coiled tubing 24 will cause shear wires 245c and 245d to shear through and allow the cable head subassembly to be removed, exposing the fishing neck 118. In the event the tool has

been run into the borehole without the outer flow tube 30, the fishing neck 118 may be grasped by fishing tools sent from the surface to retrieve the parts, otherwise the parts may be removed by attachment to the fishing neck 205 located at the top of the flow tube 30. If the cable head subassembly has been separated from the remainder of the tool by an upward force as described above, the components of the cable head subassembly slide out through the internal fishing neck 205 located at the top of the tool. When such occurs, the power and signal wires will break somewhere between the plug connectors enclosed by boots 253 and the electrical bulkhead connector 117 but the various terminations of the fiberoptic cable 33 and the LED 233 remain sealed and protected from borehole fluids and pressures with which the cable head subassembly 29 will come in contact during removal from the borehole.

The present logging tool provides for selectively connecting and optically coupling an inspection tool such as a television camera to a conventional coil tube unit which can also be used for other purposes, such as the traditional treatment of a well by injecting fluids downhole. The configuration of the present logging tool allows disconnection of the inspection modules of the tool in the event they become stuck and enables the cable head subassembly module to be removed as part of the coiled tubing for subsequent retrieval of the inspection modules with a fishing tool. A significant feature of the construction of the logging tool of the present invention is that the fiberoptic cable is terminated electrically and optically in a manner that maintains the cable straight to reduce optical attenuation while at the same time allowing the



ends of the optical fibers to be trimmed shorter in the event they become damaged or substandard in their optical coupling characteristics. The position of the diode holder is longitudinally adjustable as a function of the finished length of the fiberoptic cable and its connector to prevent any bends in the cable and the consequent attenuation introduced by such bends. The adjustable position of the diode holder allows the length of the cable to be modified by trimming the butt end of the optical fibers to ensure a proper coupling with the LED.

The system as described herein includes a downhole inspection sensor, such as a video camera, deployed by means of coiled tubing cable head subassembly which includes a cable seal that allows the diversion of optically clear fluids around the camera and the electrical and optical interconnections within an outer tube to provide a clear viewing medium for the camera. In addition, the cable head subassembly includes a cable clamp which is used to secure the electrical and optical cable within the cable head subassembly and prevent the cable from pulling out of the subassembly in the event of an emergency. Further, the electrical and optical terminations of the cable are sealed off within the subassembly housing against pressure and fluid to prevent damage to the internals of the cable in the event of a cable head subassembly pullout. This sealing means includes a pressure vessel which utilizes a cable seal subassembly to protect the fiberoptic connector area from pressure in the event of an emergency withdrawal and separation of the cable head subassembly from the remainder of the tool.

A connector housing scheme is provided  
which enables ready servicing of the

optical fiber connection within its sealed pressurized housing by removing the split halves of that housing for easy access to the electrical/optical connections for servicing.

The system includes the use of shearoff wires whereby the electronics and camera modules may be retrieved without damage in the event of a cable head subassembly pullout exposing the upper end of a fishing tool which can be readily retrieved by means of fishing equipment extended from the surface.

The cable head can also be fed through a coiled tubing injector without the camera and electronics modules which are somewhat too large and inflexible to go through the injector but provide for the subsequent plug connection attachment of the camera and electronics modules to the cable head subassembly module once it has been passed through the injector housing.

Referring briefly to FIG. 2, it should be noted that while a television camera has been shown as the exemplary modular sensor coupled to the lower end of the cable head subassembly, other modular inspection sensors could be employed such as temperature sensors, pressure sensors, acoustic sensors and/or others which could function desirably within the region of the optically transparent and/or acoustically homogenous bubble 54. In addition, it can be seen that the fluid 52 is used not only to create the optically transparent bubble 54 but also to cool the equipment within electronics and camera modules 101 and 102 and ensure that they operate at an appropriate temperature to provide maximum operational accuracy.

It is thus believed that the operation and construction of the present invention will be apparent from the foregoing discussion. While the downhole

logging tool shown and described has been characterized as being preferred, it would be obvious that various changes and modifications may be made therein without departing from the scope of the invention.

CLAIMS:

1. A downhole logging tool for use in gathering data within a borehole and sending those data to monitoring equipment at the surface by means of a fiber optic cable, comprising a system for coupling a data signal into at least one optical fiber of said cable, characterised in that said system comprises:

a light emitting diode for receiving an electrical signal indicative of said downhole data and converting said electrical signal into an optical signal;

means for terminating the butt end of the at least one optical fiber of said cable; and

means for mounting said light emitting diode for selective longitudinal positioning along a line substantially coaxial with the at least one optical fiber of said cable to position the terminated end of said at least one optical fiber in an abutting relationship with said light emitting diode and couple the optical signals produced by said diode into the at least one optical fiber of said cable for transmission to the surface without requiring any bends in said cable and independent of the length to which the butt end of said at least one fiber have been trimmed in order to terminate them.

2. A downhole logging tool as set forth in claim 1 which also includes:

a sealed chamber for containing said mounting and terminating means and said light emitting diode and protecting them from downhole fluids and pressures.

3. A downhole logging tool as set forth in claim 1 or claim 2 wherein said fiberoptic cable includes an inner core of at least one optical fiber within a steel

tube surrounded by an insulative jacket over which is formed a braided conductive layer also surrounded by an insulative layer over which a stranded conductor is wound for strength, said system further comprising:

means for fluid sealing the outside surface of said cable against borehole fluids;

means for mechanically clamping the exposed stranded conductor of said fiberoptic cable to secure the cable within said system to support said system, said stranded conductor being cut away below said mechanical clamping means to expose said insulative layer;

an enclosed chamber for containing the electrical and optical terminations of the remaining conductors within said cable; and

means for fluid and pressure sealing said insulative layer of said cable against fluid intrusion into said enclosed chamber.

4. A downhole logging tool as set forth in claim 3 in which said enclosed chamber comprises:

a pair of semi-cylindrical shells joined at opposite edges to form said chamber, said shells being separable from one another to allow access to the electrical and optical connections therein; and

a cylindrical housing positioned around said assembled shells and sealed thereto near opposite ends thereof to form a fluid and pressure tight enclosure for said connections.

Relevant Technical Fields

(i) UK Cl (Ed.M) E1F (FHK)

(ii) Int Cl (Ed.5) E21B

Databases (see below)

(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE DATABASES: WPI

Search Examiner  
D J HARRISON

Date of completion of Search  
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Documents considered relevant  
following a search in respect of  
Claims :-  
1 TO 4

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